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Solar photovoltaic water pumping for remote locations

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Abstract

Many parts of the world as well as the western US are rural in nature and consequently do not have electrical distribution lines in many parts of villages, farms, and ranches. Distribution line extension costs can run from USD 10,000 to USD 16,000/km, thereby making availability of electricity to small water pumping projects economically unattractive. But, ground water and sunlight are available, which make solar photovoltaic (SPV) powered water pumping more cost effective in these areas' small scale applications. Many western states including Wyoming are passing through the sixth year of drought with the consequent shortages of water for many applications. The Wyoming State Climatologist is predicting a possible 5–10 years of drought. Drought impacts the surface water right away, while it takes much longer to impact the underground aquifers. To mitigate the effect on the livestock and wildlife, Wyoming Governor Dave Freudenthal initiated a solar water pumping initiative in cooperation with the University of Wyoming, County Conservation Districts, Rural Electric Cooperatives, and ranching organizations. Solar water pumping has several advantages over traditional systems; for example, diesel or propane engines require not only expensive fuels, they also create noise and air pollution in many remote pristine areas. Solar systems are environment friendly, low maintenance, and have no fuel cost. In this paper the design, installation, site selection, and performance monitoring of the solar system for small-scale remote water pumping will be presented. This paper also presents technical, environmental, and economic benefits of the SPV water pumping system compared to stand alone generator and electric utility.

Keywords: Solar photovoltaic; Water pumping; Remote locations; Environment

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Contents

1. Introduction

Solar photovoltaic (SPV) water pumping (SPVWP) has been implemented around the globe as an alternative electric energy source for remote locations since SPV was invented [1–9]. The SPV system are cost effective in many remote applications such as water pumping for households, livestock and wildlife, space heating, lighting remote vacation homes, and emergency traffic applications [10–12]. The photovoltaic (PV) is a mature technology to convert sunlight into electricity. The efficiency of the PV cell has increased significantly in the last 25 years. About 1460 MW of solar PV systems were installed in worldwide in 2005 that represents a growth of 34% over 2004 installations. Annual PV domestic shipments in the USA in 2005 were 104 MW, which is 33% more than 2004 [13]. But, still the PV system cannot compete with the traditional energy resources such as coal, oil, natural gas and conventional hydro for the large-scale commercial, industrial and residential applications. A PV system is suitable for a small scale remote application where 24 h electrical service is not necessary and maintenance is an issue. Wyoming is the least populated state in the USA and most of the ranching areas are in remote locations. The grid electricity supply is not available to all ranches throughout the state that makes the situation worse during summer to pump underground water. The state of Wyoming stepped into the sixth year of drought and most surface water is drying up in early June. Fig. 1 shows drought condition in the USA and Wyoming is one the most affected states [14].

Long-term drought has severe impact on the surface water, which is the only source of water for the wildlife and in many cases for the livestock. To help the drought affected remote livestock and wildlife, Governor Freudenthal started a solar water pumping initiative in cooperation with the University of Wyoming Motor Testing and

Training Center (UWMTTC). This initiative allows the UWMTTC to install four solar pumping systems in each county of the state during 2005–2006. The UWMTTC also supervised the installation of 15 SPVWP systems during 1991–2002. The project objectives were to:

- supply solar water pumping system to drought affected remote livestock and wildlife,
- educate people about clean and alternative energy,
- monitor system performance and give free maintenance service for 2 years,
- monitor customer satisfaction,
- evaluate performance of old PV systems.

This paper describes technical, economical, and environmental aspects, along with performance evaluations and other details that include site selection, system design, and installation.

2. Solar photovoltaic water pumping systems

PV system is based on semiconductor technology that converts sunlight into electricity. This is a proven technology but costs more than other electricity generation methods such as power plant based on coal, oil, natural gas and conventional hydro. Fig. 2 shows a schematic diagram of a solar water pumping system. This section provides a brief

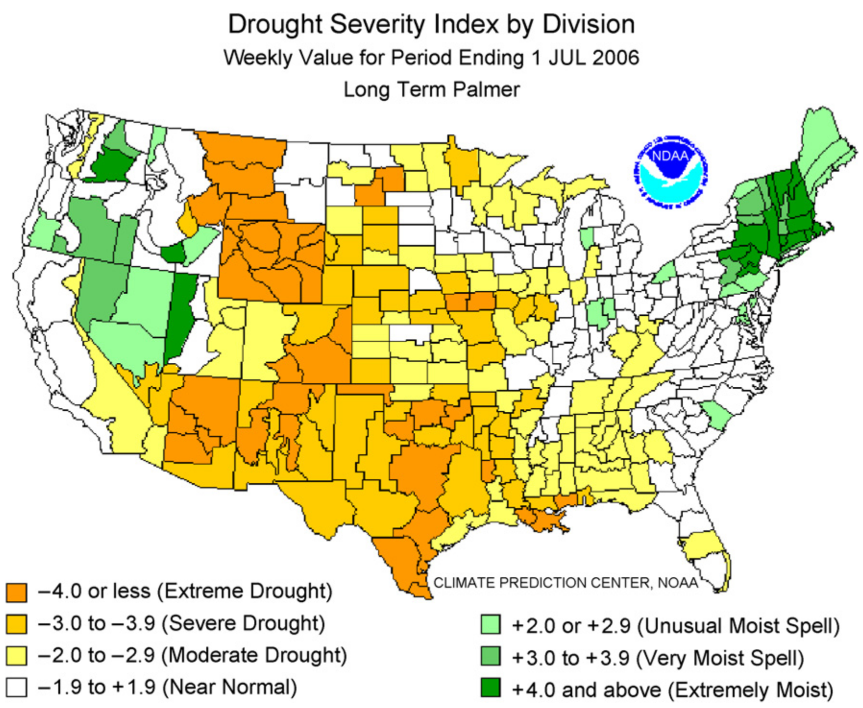

Fig. 1. Drought situation in the USA, July 2006.

discussion about the main component of an SPV water pumping system for livestock and wildlife in remote locations.

2.1. The PV array

The source of electrical energy of the SPVWP systems is the PV arrays. Every PV array has its own (*I–V*) characteristics. The maximum power point (MPP) depends on several factors including on site solar radiation, temperature, and the connected load—if the load is directly connected. For the same amount of power, array size depends on the efficiency of the cell. Solar cells could be divided into three categories according to the type of crystal: monocrystalline, polycrystalline and amorphous. The level of efficiencies in production is about 7%, 15%, and 17% for amorphous, polycrystalline, and monocrystalline silicon, respectively.

2.2. The pump

Solar water pumps may be subdivided into three types according to their applications: submersible, surface, and floating water pumps. A submersible pump draws water from deep wells, a surface pump draws water from shallow wells, springs, ponds, rivers or tanks,

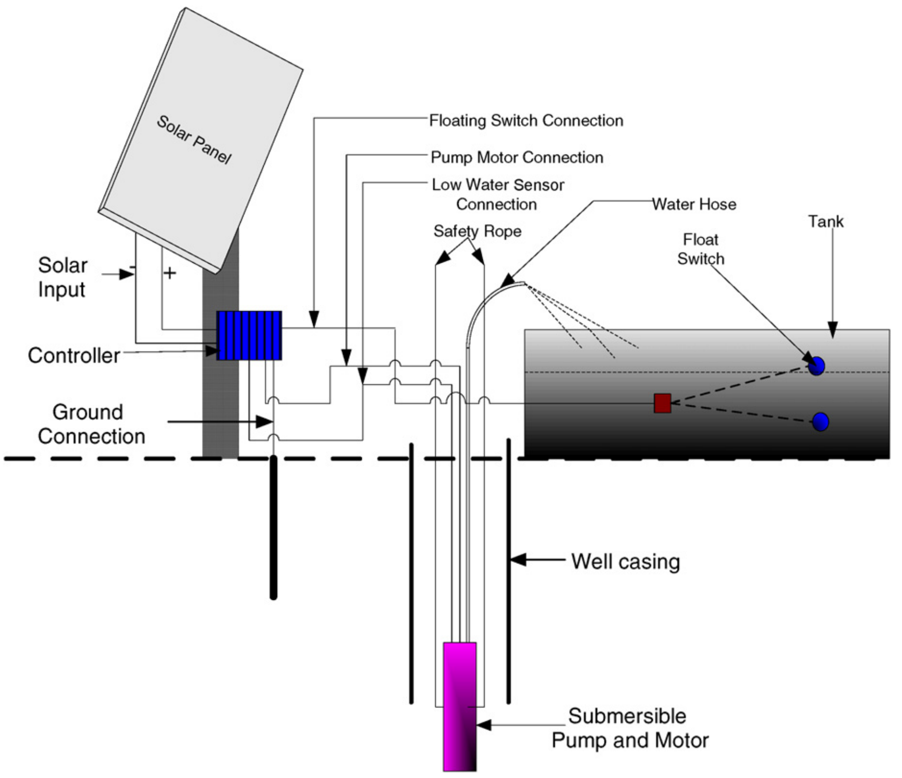

Fig. 2. Schematic diagram of a solar water pumping system.

and a floating water pump draws water from reservoirs with adjusting height ability. There are several types of pumps according to their pumping principle:

- Centrifugal pumps, where liquid is sucked by the centrifugal force created by the impeller and the casing directs the liquid to the outlet as the impeller rotates. The liquid leaves with a higher velocity and pressure than it had when it entered.
- Screw pumps, where a screw traps the liquid in the suction side of the pump casing and forces it to the outlet.
- Piston pumps, where motion of the piston draws water into a chamber using the inlet valve, and expels it to the outlet using the outlet valve.

The selection of pump in a solar water pumping is solely application dependent, such as water requirement, water height, and water quality.

2.3. The pump–motor

Several types of motors are currently available in the market, such as AC, DC, permanent magnet, brushed, brushless, synchronous and asynchronous, variable reluctance, and many more. The PV array could be directly connected to the motor, if the application needs a DC motor. If the application needs an AC motor, an inverter (usually called controller) needs to be placed in between the PV array and the motor. The motor and pump are built in together for the submersible and floating systems, in this case, the consumer does not have an option to choose the pump and motor separately. In the surface system, it is possible to choose the pump and motor separately and examine the performance along with the controller and panel.

2.4. The controller

The controller is mandatory if the AC motor is in use. The controller effectively isolates the PV array from the pump–motor system for greater safety and provides the pump–motor with the optimum voltage/current for the site conditions. The controller also protects the pump–motor from running dry and conserves water by turning off the system when the tank is full. However, one of the most vulnerable components in the SPV water pumping system is the controller because it contains sophisticated electronics and has to operate in various environmental conditions.

3. Technical factors

The SPVWP is proven technically and economically in Wyoming [8]. Technical discussion is limited to a small scale (less than 1500 W) water pumping system and in a remote location, which is 1 km or more away from the power distribution line. One kilometer of distribution line extension costs between USD 10,000 and USD 16,000: but a complete small-scale solar water pumping system costs between USD 3000 and USD 10,000. On the other hand, power companies are not eager to build a single transmission line just for a remote water pumping because of the low seasonal revenue. A solar water pumping system usually does not include any battery back up. This makes it maintenance free and stand alone PV system, and lowers both the complexity and the capital costs.

Typically, ranches have more than one pasture and usually different pastures are used for grazing in different time of the year for the efficient use of land. The solar water pumping system on a trailer could be a good choice in this case. Fig. 3 shows an SPV system mounted on a trailer for use in multiple water wells.

One of the main challenges of this project is to make the SPVWP system more user friendly, and adopt locally available materials for convenience of handling future maintenance problems. The UWMTTC took some initiatives to facilitate the local level operation and maintenance (O&M):

(a) modify the system based on local materials,
(b) use materials from local suppliers,
(c) educate people through the workshop, training, and demonstration.

Local level O&M is very important for any small scale system, because the system provider will not be there for a long time. Also, it is not cost effective to call the system provider to maintain small systems, such as SPVWP systems. Fig. 4 shows the rack mounted and pole mounted solar panels, where rack mounted solar panels are a modified version of pole mounted solar panels. In this case, local materials are used to reduce the system cost as well as to add mobility to the system. The UWMTTC used materials from local suppliers in order to make future maintenance problems easier. If any component fails in future, the owner can get the component from local suppliers. The UWMTTC arranged a series of workshops, demonstrations, and training sessions throughout the state to educate the people about the SPVWP system. The goal of this initiative is to employ local skills, resources, and materials for O&M.

Fig. 3. Solar pumping system mounted on a trailer.

Small generators and windmills can be alternatives for remote water pumping but they have some significant downsides. A generator could be turned on and off using a remote switch but regular maintenance and refueling requires physical presence at the site. Windmill has mechanical moving parts that make noises and need regular high maintenance, costly repair, difficult to find parts, special tools for installation, and intensive labor. Windmills do not have any remote control or automatic shut off in case of overflow. Windmills cannot be used for multiple water wells in different pastures. On the other hand, PV water pumping systems are equipped with automatic turn off mechanism when the tank is full. They also sense the water level of the well, when the water level is low, the system is turned off and waits a few minutes for the well to be recharged. A PV system is a maintenance free auto operative stand alone water pumping system that is cost effective and technically suitable for remote livestock and wildlife. Table 1 shows a comprehensive comparison of alternative energy options for small scale remote water pumping.

4. Economic aspects

The capital cost of the PV system includes solar panels, pump, controller/inverter, power cables, draw down pipe and accessories. The capital cost of electric utility includes transmission line instead of solar panels and other system components are the same. The capital cost of a diesel generator includes an electric generator instead of solar panels and other system components remain the same. The PV system does not have any operating cost, but electric utility costs 5–13 ¢/kWh and diesel costs \$0.6/kWh with high maintenance cost. The efficiency of a diesel generator goes down with time, where as the PV system produces same power throughout its life span. A project can be justified using

Fig. 4. Rack mounted and pole mounted solar panels.

Table 1
Comparison of energy options for remote water pumping

Energy source	Estimated capital cost	Operation cost	Maintenance	Life span (year)
PV system	\$6.8/Wp	None	Low	10–15
Electric utility	\$22/W	5–13 ¢/kWh	Low	N/A
Gasoline Generator	\$2.5/W	\$0.6/kWh	High	5–10

net present value (NPV), when NPV is positive over a seasonable time period, the project could be profitable. The NPV can be expressed as

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{R_t}{(1+r)^t} - C, \tag{1}$$

where n is the total time period, R_t the cash flow, r the discount rate, and C the capital cost. The cash flow R_t, could be calculated by comparing diesel generator and solar system, because there is no direct cash flow associated in the investment. The R_t may be written as

$$R_t = (\text{O\&M cost of diesel generator}) - (\text{O\&M cost of solar system}), \tag{2}$$

where O&M costs include fuel, transportation, replacement, and maintenance costs. The discount rate, r is taken as 7%. For a 25-year project life, NPV is really high for a 1000 W SPV water pumping system. Eq. (1) can be used to predict the pay back period by calculating the n, which makes NPV zero. For a 1000 W system the pay back period is 8 years.

Fig. 5 compares the three water pumping methods—solar PV, diesel generator, and AC with a new distribution line. Each system pumps the same amount of water. The cost for the diesel generator includes capital cost, fuel for the generator, and fuel for the vehicle used on a 16 km round trip every day. The AC with distribution line includes capital cost for the pump and/or controller, capital cost for the line ($13,000/km), fuel to visit the system on site twice a week and the electricity cost. The SPVWP system cost includes the capital cost of the system and fuel cost to check on the system once a week. The sharp rise in the plot indicates the replacement of generator, pump and/or controller. Fig. 5 is calculated under the following assumptions:

- System capacity 1000 W.
- *Capital costs*: SPVWP USD 6850, diesel generator water pumping USD 2450, and electric utility with 1.61 km (1 mile) new line extension USD 22,000.
- *Transportation costs*: SPVWP USD 78/season, diesel generator USD 500/season, and utility USD 150/season with 10% increase in fuel price every year.
- Fuel cost for diesel generator USD 500 per season.

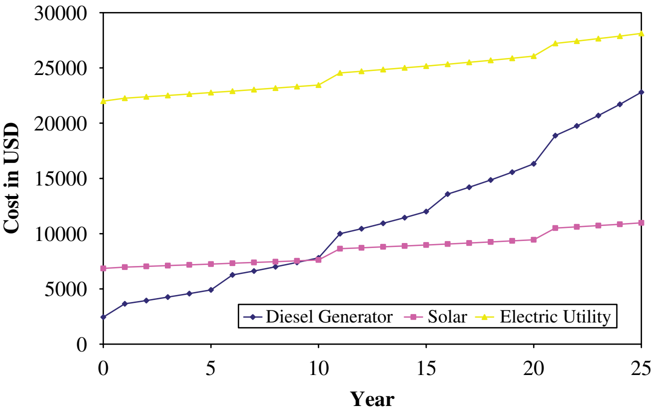

Fig. 5. Cost comparison among the new utility line, solar pumping system, and diesel generator.

- *Maintenance cost*: SPV, USD 50/season, diesel generator, USD 200/season, and electricity cost for utility is USD 110/season.

It is evident from Fig. 5 that the SPVWP system is the most cost effective for remote water pumping, even though it has higher capital cost than the diesel generator. Electric utility has the highest capital cost, also it has higher O&M cost than the SPVWP. The replacement is scheduled after 10 years—for the SPVWP the replacement is the pump and/or controller, for the diesel generator, the only option is to buy new generator and the pump, and for the utility connection it is the pump and/or controller, if one is used. Fig. 6 shows the total life cycle cost comparison over a 25-year period among SPVWP, diesel generator, and utility under the same assumptions above. It can be seen from Fig. 6 that the SPVWP system has the lowest life cycle cost, which makes it more suitable for remote applications.

5. Environmental aspects

In the United States, energy related carbon dioxide emissions by fossil fuel were 5973 million metric tons in 2004, which is 1.7% higher than 2003—in which 40% is contributed by electric power plants. Coal accounts for over 50% of electricity generation and is the largest source of carbon dioxide emissions ranging from 83% to 86% since 1990 in electricity production. Carbon dioxide emissions and total energy usages are highly correlated and it is a strong indicator of economical growth of a country. Fossil fuels are the biggest source of energy in the United States and during 2004, 82.4% of total US greenhouse gas emissions consisted of carbon dioxide from the combustion of fossil fuels such as coal, petroleum, and natural gas [15].

Increasing the power generation from renewable resources means decreasing the power generation from the fossil fuels, mostly from coal. Each kilowatt hour generation from fossil

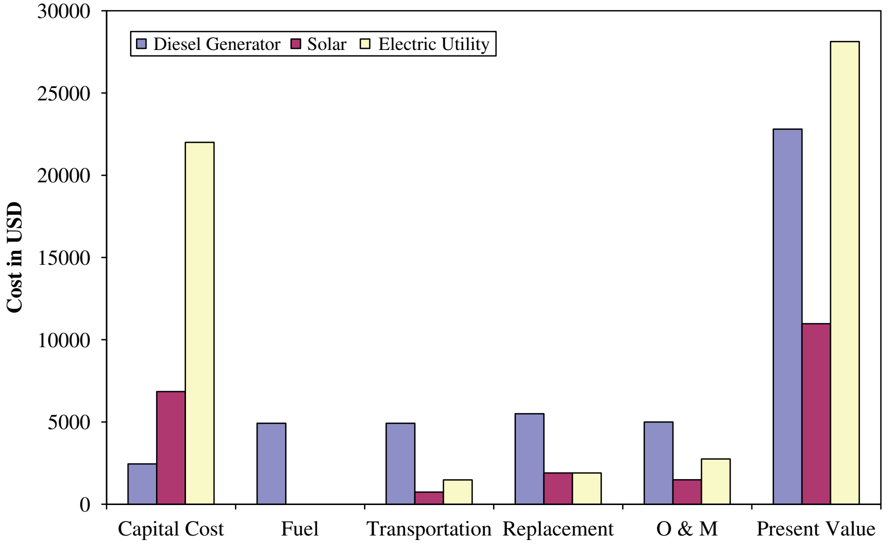

Fig. 6. Difference in 25-year cost compared to solar PV.

fuels emits carbon dioxide into the air. Carbon dioxide emissions from coal, diesel, and natural gas are 976, 733, and 531 g/kWh, respectively [16]. Fig. 7 shows the carbon dioxide emissions from different fossil fuels for a 1000 W power generation over 25 years, which is a nominal life cycle for the SPV water pumping system, with few replacements. The calculations in Fig. 7 are conducted assuming a 25% capacity factor, because of the low capacity factor of the SPV system. The UWMTTC installed over 45,000 W SPVWP system from 1991 to present. This SPVWP installations saved carbon dioxide emissions—24,045 metric tons with respect to coal fired power generation or 1308 metric tons with respect to natural gas fired power or 1806 metric tons with respect to on site diesel generators.

Among the three alternatives, generators, windmills, and solar systems for remote water pumping, only solar systems do not have any adverse effect on the environment. Generators, which produce CO_2 emission and harsh noise, are responsible for the air pollution and sound pollution, respectively. Windmills do not produce any emissions but they have visual impact and cause sound pollution. Alternatively, PV systems do not create any emissions and use of SPVWP systems for remote water pumping could reduce both air and sound pollution.

6. Site selection

Site selection is the most critical and sensitive issue because this initiative planned to install a minimum of three and a maximum of four solar water pumping systems in each county, while the interest level from ranchers is very high. The UWMTTC is not directly involved with ranchers or other people throughout the state who are willing to receive a system. To achieve a fair and equitable selection, the UWMTTC coordinated the site selection process through the Conservation Districts in each county. The same guide lines were used for every county and Conservation District ranked the applications before sending them to the

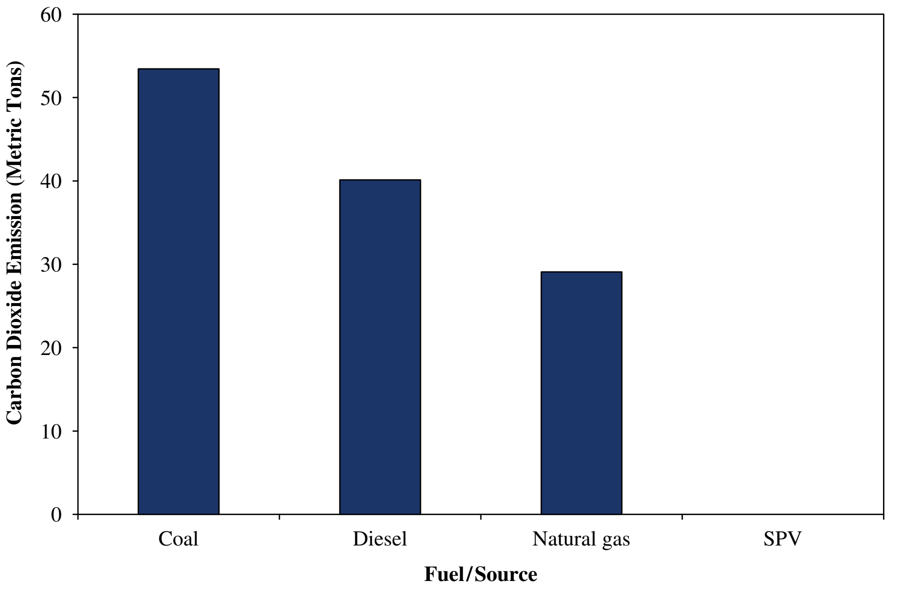

Fig. 7. Carbon dioxide emissions from fossil fuels over 25 years for 1000 W power generation.

UWMTTC. The interested ranchers were asked to answer the following questions:

1. Does the proposed project improve livestock distribution? Explain: (15 pts. Possible).
2. Does the project provide off stream water for livestock to reduce grazing on riparian areas? Explain: (15 pts. Possible).
3. Is water development part of a planned grazing system? Explain: (15 pts. Possible).
4. Does the project provide water for the wildlife? Explain: (15 pts. Possible).
5. Will the project provide necessary water for all species during severe drought? Explain: (20 pts. Possible).
6. Will matching dollars from local, state, or federal cost share programs be used to help fund the project? Explain: (20 pts. Possible).
7. What is the distance to the nearest distribution line and other benefits? Explain: (15 pts. Possible).

7. Design and installation

The goal of the final output of the design and installation is to provide enough water for the livestock and wildlife. The design process needs accurate information about water requirement, water source, solar radiation, and duration of system use in a year. System design starts from the information about the water requirement for a particular application, well characteristics and/or other source of water, and the water storage facilities. One objective of this initiative is not only to provide sufficient water to the livestock and wildlife, but also conservation of water for future use. Unnecessary overflow can be controlled using a proper water storage tank and an automatic turn off float switch. The design includes solar panels sizing, pump sizing, and controller selection. Solar water pumping systems should supply sufficient water year around. To ensure satisfying this requirement the worst scenario, for example fall or winter operation is considered for the design. Table 2 shows the water use information.

Pump sizing needs three basic pieces of information: water requirement m^3/day, total water head, and continuous water flow or recharge rate of the well. During the pump sizing, cloudy days should be considered by allowing for 5% over design of the pump. In this process, one complete cloudy day can be covered in every 20 days, but the tank must be large enough to store extra water. A pump can be selected using total head and water requirement but the water requirement in gallons per minute should be less than the well recharge rate. Otherwise, a well dry sensor should be used with a proper delay. The total power requirement can be found from the pump selection and traditional design practice adds 20% more power to secure sufficient water flow. Next, a controller is selected using the information about the solar array power, open circuit voltage, nominal voltage, and power. A controller which incorporates an inverter is needed if an AC pump is used.

The installation involves paying attention to some crucial issues to make the solar system more efficient and safe. The first consideration is how to mount the solar array? It could be a fixed angle or a tracking system. The tracking could capture more solar radiation during the early morning and the late afternoon hours, but in many windy areas like Wyoming, wind gust may force the panel in the wrong direction. On the other hand, the fixed angle system gets less sunlight but ends up to be more reliable and need less

Table 2
Water use information

Water use information
Daily pumping requirement
Summer _________ m^3/day
Winter _________ m^3/day
Spring/Fall _________ m^3/day
Livestock
Cow Calf Pairs ______ feeder calves ______cattle ______ bulls _______ horses ______ Misc_______
Water storage information: (*please circle one*)
Above ground tank—size: ______________ m^3
Under ground tank—size: ______________ m^3
Pressure tank—pressure: ______________ N/m^2
Water source information
Number of water source locations: _____
Source of water (please circle one)
Drilled well: well casing diameter ______ centimeters
Result based on resent test? Yes___ No____
Surface water: pond _____ stream _____
Static water level
Distance from ground surface to water when not pumping ______ meters
Draw down level
Maximum water level drop when pumping __________________ meters
Discharge head:
Vertical distance from ground level to storage tank ____________ meters
Total head: (add all previous distances) _____________________ meters
Well recovery/recharge
Continuous water flow _________________________ m^3/min

maintenance. The same solar system could be used in more than one location for pumping water. The solar system could be installed on a trailer to move around as shown in Fig. 3. Otherwise, the solar system is pole mounted or rack mounted to pump water at one fixed location as shown in Fig. 4. As the sun changes its angular position over the year, the solar array angle needs to be adjusted according to the sun's angle. The wind loading could be an issue for a solar system with large panel areas. Providing appropriate gaps between the solar panels reduces wind loading.

8. Performance monitoring

One of the key benefits of using solar PV in remote pumping applications is the durability and low maintenance nature of panel. With no moving parts, panels have little wear and tear. The most problem prone component in a pumping system is the pump itself. Before 2002, solar pumps were operated on a sealed diaphragm principle. Small moving parts and diaphragms inside the submersible pump would routinely fail leading to higher than expected maintenance costs. Secondarily, most solar pumps used a brushed DC

motor to drive the pump; this added the maintenance of changing the brushes every 2–3 years of operation.

With the introduction of the helical rotor (HR) solar pump many of these problems have been eliminated or drastically reduced. The key benefit of the HR is that there is one moving part, the rotor and no sealed diaphragms. The only wear and tear is seen by the stainless steel rotor and rubber stator. In the case of the Lorentz HR pump, the motor is a three phase motor with no sealed cavities. The Grundfos SQ Flex HR pump consists of a similar rotor/stator set as the Lorentz design, however the pump has a seal section containing the electronics and controls typically found in a controller located on the surface. This design simplifies installation; however it adds complexity to the pump unit.

One of the reasons to choose the SPVWP for remote locations is its ability to produce water with very little attention. The performance and reliability of a system could be judged by user feedback. Under this Governor's funded project, 75 solar SPVWP systems are already installed and 15 solar SPVWP systems were also installed earlier during 1991–2002 under UWMTTC's supervision. This offers a good opportunity to compare the system performance and reliability of the old systems to the new systems. A survey, which is guided by demographic information, system specification and some questions about system performance, was conducted to evaluate the system performance. All information and questions are divided into six categories: (1) demographic information, (2) system specifications, (3) previous system information, (4) consumer satisfaction, (5) failure report, and (6) environmental impacts.

Each category includes detailed questions, for example, category 1 includes questions about end use, geographic location, user's familiarity, and system operation. System specification in category 2 provides information about rated power, solar panel rating, support structure, controller/inverter, pump, water storage, total head and designed and actual flow rate (gallons/day). Category 3 asked questions about the previous system (if any) that includes type, fuel cost, maintenance requirements, water pumping rate, and years of service. For consumer satisfaction only two questions were asked: productivity and reliability. The failure report in category 5 includes problem with pumps, controller/inverter, well and other failures. Environmental impact is mainly looking for documentation of any types of pollution.

The UWMTTC is conducting a survey among the solar system recipients to document field performance. A total of 90 SPV water pumping systems were installed under UWMTTC's supervision, so far 42 systems' performance information are available and the UWMTTC is in the process of collecting the rest of the information. Survey results are divided into three categories depending on the system's operation time: (I) 15-year assessment, (II) 5-year assessment, and (III) 1-year assessment.

8.1. Fifteen-year assessment

The UWMTTC installed seven SPVWP systems in Wyoming in cooperation with five rural electric cooperatives in the state of Wyoming and Sandia National Labs during 1991and 1992. These systems have been in operation for 15 years and a survey was conducted to evaluate their performance. Five systems' information is available and presented here. All systems are in the operation, but multiple replacements were done. Eleven failures were reported: 6 pump failures, 3 controller failures, one pipe failure, and

one electric power cable failure. Two system owners had to replace the pump twice. The respective owners replaced the failed parts and restored the system operation. Two ranchers added more livestock because of increased water supplies and others wanted to add more livestock, but they do not have enough land. Two ranchers ranked the SPVWP system excellent on reliability, and two ranchers ranked the system good, one rancher ranked the system adequate. On the basis of productivity, three ranchers ranked the system as excellent, one ranked the system as good, and one ranked the system as adequate.

8.2. Five-year assessment

During 2001–2002, the UWMTTC supervised the installation of eight SPVWP systems in the state of Wyoming. A survey was conducted on seven systems. One system is out of operation because the well dried out—the owner is planning to move it to the new location. Five failures were reported: four pump failures and one controller failure. The common problems for motor/pump are sand in the well and motor. One system owner had to replace the pump three times due to the sand problem in the well. The respective owner replaced the failed parts and restored system operation. Four ranchers added more livestock because of increased water supplies. Five ranchers ranked the SPVWP system as excellent on reliability, and two ranchers ranked the system as good. On the basis of productivity, four ranchers ranked the system as excellent, and three ranked the system as good. All ranchers agreed that they saved time, energy, and money by installing SPVWP system in their ranches.

8.3. One-year assessment

Currently, the project has approximately 30 Lorentz based systems, 40 Grundfos based systems and 5 surface pump systems installed. The Lorentz systems have all been in place over since 2005, while the Grundfos and surface systems were installed in Spring/Summer 2006. Problems with the Lorentz systems have been limited to failures in the low end PS200 controller, a specific problem with the stator rubber, one failed check valve and a stator failure due to acid exposure. Corrupted microprocessor memory led to a 20% failure rate of the PS200 systems installed. This problem was solved by replacing the defective units. The leaky check valve caused a lower than expected flow rate and was corrected by replacing the defective pump unit. The rest of the failures were due to a flawed rubber formulation in the pump stator. Stock water pumps are typically in use for only a portion of the calendar year. In the case of five units, the pumps were shut down in late fall and were to be put back in service in the early summer. During this 6–8-month period water in the well caused the stator rubber to swell. This in turn increased the amount of torque required to start the pump. This caused the controllers to overload the pump not run. Removal and replacement with a new unit was the solution to this problem. Finally, one pump stator was destroyed by well water with low pH. Abandoned oil field wells are often used as stock water wells. Water in these areas can often be high in sulfur content and this lead to formation of a mild sulfuric acid in the well. The rubber in the pump stator began to dissolve in this solution and eventually led to failure of the pump. Removal and placement of the repaired pump in a higher quality water source fixed this issue.

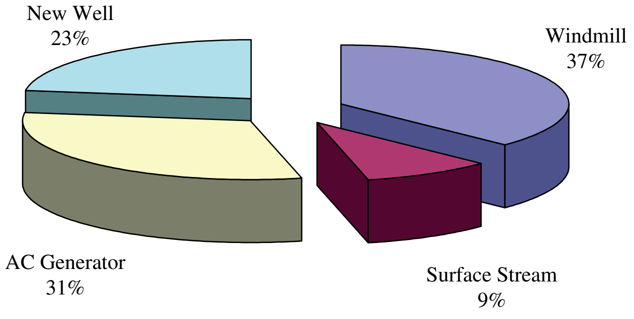

Fig. 8. Previous system information.

Currently, the surface systems have had no maintenance issues beyond the expected. One failure of a Grundfos SQ Flex pump has occurred and it is attributed to a faulty check valve in the pump. Replacement of the unit has corrected this problem.

In total, 50% ranchers added more livestock because of increased water supply and 90% ranchers agreed that SPVWP save their time, energy, and money. In total, 17 ranchers out of 30 ranked the SPVWP system as excellent on reliability, 10 ranchers ranked the system as good, and 3 ranchers ranked it as adequate. On the basis of productivity, 21 ranchers ranked the system as excellent, and eight ranked the system as good, and 1 rancher ranked it as adequate.

The average water head for all systems surveyed is 36.88 m; the average water pumping rate is 0.0401 m^3/min; the average distance from the distribution line is 2.70 km, and 100% of the end users are livestock and wildlife. The existing system information which was replaced by the SPVWP systems is shown in Fig. 8. Windmills comprised 37% of the old system and the main reason to replace them was lack of wind on some days during peak summer months. The problems with AC generators are maintenance, refueling, and time. Surface streams dry out during the early summer and new pastures do not have any existing water system. All system recipients strongly agreed to recommend others to consider installing solar PV water pumping systems because of their productivity, reliability and environmental friendliness.

9. Conclusion

SPVWP is a cost effective and environmental friendly way to pump water in remote locations. In this paper, Wyoming Governor Dave Freudenthals' solar water pumping initiative to alleviate drought impact is presented. A total of 88 solar water pumping systems are being installed in all 23 countries of the state, of which 75 systems are in operation at present. The solar PV water pumping system has excellent performance in terms of productivity, reliability, and cost effectiveness. Drought affected areas like Wyoming, Montana, Idaho, Washington, Oregon, and part of Texas could use solar PV water pumping systems to improve the water supply to livestock in remote locations. The successful demonstration of these systems is encouraging other ranchers to try this relatively new technology as another viable water supply option. The SPVWP system could reduce the CO_2 emission considerably over its 25-year life span.

This paper also presented a survey report of 15-, 5-, and 1-year-old SPVWP systems. The survey report showed that solar PV is reliable for remote locations despite the failure of component. Among the all major components, the pump/motor is the most vulnerable part of the SPVWP system. Ranchers added more livestock because of increased water supply and water conservation.

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